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10 Human Factors in Maintainability

10.1 INTRODUCTION

Human factors is an important discipline of engineering and it exists because people make errors in using and maintaining machines; otherwise, it would be rather difficult to justify the discipline's existence. In the published literature the terms *human factors*, *human engineering*, *ergonomics*, and *human factors engineering* have appeared interchangeably. Human factors are a body of scientific facts concerning human characteristics (the term includes all psychosocial and biomedical considerations).

Although the modern history of human factors may be traced back to Frederick W. Taylor, who carried out various studies to determine the most suitable design of shovels, human factors have only been an important element of maintainability work since World War II [1,2]. During this war the performance of military equipment clearly proved that equipment is only as good as the individuals operating and maintaining it. This means that people play an important role in the overall success of a system. Systems may fail for various reasons including poor attention given to human factors with respect to maintainability during the design phase [3].

This chapter presents various important aspects of human factors directly or indirectly related to maintainability.

10.2 GENERAL HUMAN BEHAVIORS

Many researchers have studied human behaviors and made conclusions about many general, typical, and expected behaviors. The knowledge of such behaviors can be quite useful in maintainability work directly or indirectly. Some general human behaviors are as follows [4,5]:

- People get easily confused with unfamiliar things.
- People become complacent and less careful after successfully handling hazardous items over a lengthy period.
- People have tendency to use their hands for examining or testing.
- People usually overestimate short distances and underestimate large or horizontal distances.
- People are too impatient to take the appropriate amount of time for observing precautions.
- People expect electrical switches to move upward or to the right for turning power on.
- People have become accustomed to certain color meanings.

- People read instructions and labels incorrectly or overlook them altogether.
- In emergencies, people normally respond irrationally.
- People often estimate speed or clearance poorly.
- Peoples' attention is drawn to items such as loud noises, flashing lights, bright and vivid colors, and bright lights.
- People fail to recheck their work for errors after performing a procedure.
- People, in general, have a very little idea about their physical limitations.
- People are reluctant to admit errors or mistakes.
- People assume that an object is small enough to get hold of and is light enough to pick up.
- People are rather reluctant to admit that they do not see objects clearly, whether because of poor eyesight or inadequate illumination.
- People carry out their tasks while thinking about other things.
- People usually expect that valve handles and faucets rotate counterclockwise for increasing the flow of liquid, steam, or gas.
- People can get easily distracted by certain aspects of a product's features.
- People regard manufactured products as being safe.

10.3 HUMAN SENSORY CAPABILITIES AND BODY MEASUREMENTS

In maintainability work, there is a need for an understanding of human sensory capacities as they apply to areas such as parts identification, noise, and color coding. The five major senses possessed by humans are sight, taste, smell, touch, and hearing. Humans can sense items such as pressure, vibration, temperature, linear motion, and acceleration (shock). Three of these sensors are discussed below [2,3,6].

10.3.1 TOUCH

This complements human ability to interpret visual and auditory stimuli. In maintainability work the touch sensor may be used to relieve eyes and ears of part of the load. For example, its application could be the recognition of control knob shapes with or without using other sensors.

The use of the touch sensor in technical work is not new; it has been used for many centuries by craft workers for detecting surface irregularities and roughness. Furthermore, according to Reference 7, the detection accuracy of surface irregularities dramatically improves when the worker moves an intermediate piece of paper or thin cloth over the object surface rather than simply using his or her bare fingers.

10.3.2 SIGHT

This is another sensor that plays an important role in maintainability work. Sight is stimulated by electromagnetic radiation of certain wavelengths, often known as the visible segment of the electromagnetic spectrum. In daylight, the human eye is very sensitive to greenish-yellow light and it sees differently from different angles.

Some of the important factors concerning color with respect to the human eye are as follows:

- Normally, the eye can perceive all colors when looking straight ahead. However, with an increase in viewing angle, color perception decreases significantly.
- In poorly lit areas or at night, it may be impossible to determine the color of a small point source of light (e.g., a small warning light) at a distance. In fact, the light colors will appear to be white.
- The color reversal phenomenon may occur when one is staring, for example, at a green or red light and then glances away. In such situations, the signal to the brain may reverse the color.

Some useful guidelines for designers and others are to choose colors in such a way that color-weak people do not get confused, use red filters with a wavelength greater than 6,500 Å, and avoid placing too much reliance on color when critical tasks are to be performed by fatigued personnel [8].

10.3.3 HEARING

This sensor can also be an important factor in maintainability work, as excessive noise may lead to problems including reduction in the workers' efficiency, adverse effects on tasks, need for intense concentration or a high degree of muscular coordination, and loss in hearing if exposed for long periods. In order to reduce the effects of noise, some useful guidelines related to maintainability are as follows [3]:

- Protect maintenance personnel by issuing protective devices where noise reduction is not possible.
- Incorporate into the equipment appropriate acoustical design and mufflers and other sound-proofing devices in areas where maintenance tasks must be performed in the presence of extreme noise.
- Keep noise levels below 85 dB in areas where the presence of maintenance persons is necessary.
- Prevent unprotected repair personnel from entering areas with sound levels more than 150 dB.

10.3.4 BODY MEASUREMENTS

This information is very important in designing for maintainability since humans usually operate and maintain engineering products. It helps designers ensure that equipment and products under consideration will accommodate operating and maintenance personnel of varying weights, sizes, and shapes. In turn, these people will perform their tasks effectively.

Usually human body-related requirements are outlined in the product or system design specification, particularly when the equipment is being developed for use in

TABLE 10.1**Some Body-Related Dimensions of the U.S. Adult Population (18–79 years)**

No.	Description	5th Percentile (in Inches)		95th Percentile (in Inches)	
		Female	Male	Female	Male
1	Weight	104 (lb)	126 (lb)	199 (lb)	217 (lb)
2	Seated eye height	27.4	28.4	31.0	33.5
3	Standing height	59	63.6	67.1	72.8
4	Sitting height	30.9	33.2	35.7	38.0
5	Seated width	12.3	12.2	17.1	15.9

a military application. For example, MIL-STD-1472 [9] states, “Design shall insure operability and maintainability by at least 90 percent of the user population” and “The design range shall include at least the 5th and 95th percentiles for design-critical body dimensions.”

Furthermore, the standard states that the use of anthropometric data should take into consideration factors such as the nature and frequency of tasks to be performed, the difficulties associated with intended tasks, the position of the body during task performance, the mobility and flexibility requirements of the task, the increments in the design-critical dimensions imposed by protective garments, the need to compensate for obstacles, and so on.

Some body-related dimensions of the U.S. adult population (18 to 79 years) are presented in Table 10.1 [9–11].

Some useful pointers for engineering designers concerning the application of body force and strength are as follows [12]:

- With the use of the whole arm and shoulder, the maximum exertable force is increased.
- A person’s arm strength reaches its peak around age 25.
- The maximum handgrip strength of a 25-year-old male is about 125 pounds.
- The maximum push force for side-to-side motion is about 90 pounds.
- Pull force is greater from a sitting than from a standing position.
- The degree of force that can be exerted is determined by factors such as body parts involved, direction of force applied, body position, and the object involved.

10.4 AUDITORY AND VISUAL WARNINGS IN MAINTENANCE WORK

In maintenance work various auditory and visual warning devices are used for the safety of maintenance personnel. A clear understanding of such devices is essential. Examples of warning devices used in maintenance work are sirens, bells, and buzzers.

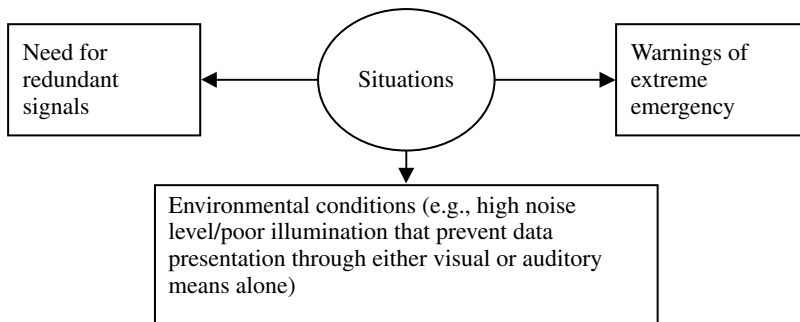


FIGURE 10.1 Situations that require the simultaneous use of both visual and auditory signals.

In maintainability design, with respect to the use of auditory warning devices, attention should be given to factors such as easy detectability, suitability to get the attention of repair personnel, use of warbling or undulating tones and sound at least 20 dB above threshold level, distinctiveness, noncontinuous and high-pitched tones above 2,000 Hz, and no requirement for interpretation when maintenance people are performing repetitive tasks [2].

Additional design recommendations for auditory warning devices to address corresponding conditions (in parentheses) are to select a frequency that makes the signal audible through other noise (presence of background noise), use low frequencies (sound is expected to pass through partitions and bend around obstacles), modulate the signal to generate intermittent beeps (signal must command maintenance person's attention), use manual shut-off mechanism (warning signal must be acknowledged), and use high intensities and avoid high frequencies (repair personnel are performing their tasks far from the signal source).

Some of the conditions for using auditory presentation are that the message is simple, the message receiving location is too brightly lit, the maintenance person is moving around continuously, the maintenance person is overburdened with visual stimuli, the message is short, and the message requires immediate action. Similarly, some of the conditions for using visual presentation are that the message is complex, the maintenance person is overburdened with auditory stimuli, the message is long, the message receiving location is too noisy, the message does not require immediate action, and the maintenance person's job allows him or her to remain in one place.

Three situations that require the simultaneous use of both visual and auditory signals are shown in Figure 10.1 [3].

10.5 HUMAN FACTORS-RELATED FORMULAS

Human factors researchers have developed many mathematical formulas for estimating human factors-related information. This section presents some of the formulas considered useful for maintainability work.

10.5.1 THE DECIBEL

The level of sound intensity is measured in term of decibels, the basic unit named after Alexander Graham Bell (1847–1922), the inventor of telephone. The sound-pressure level (SPL), in decibels, is defined by [13–14].

$$SPL = 10 \log_{10} \left(\frac{P^2}{P_0^2} \right) \quad (10.1)$$

where P^2 is the sound pressure squared of the sound to be measured and P_0^2 is the standard reference sound pressure squared, representing zero decibels. Under normal conditions, P_0 is the faintest 1,000-Hz tone that an average young adult can hear.

10.5.2 CHARACTER HEIGHT ESTIMATION FORMULAS

10.5.2.1 Formula 1

Usually, for a comfortable arm reach for performing control and adjustment-oriented tasks, the instrument panels are installed at a viewing distance of 28 inches. Thus, letter, marking, and number sizes are based on this viewing distance. However, sometimes the need may arise to vary this distance; under such circumstances, the following equation can be used to estimate the required character height [13,15]:

$$H_C = H_s D_s / 28 \quad (10.2)$$

where H_C is the character height estimate at the specified viewing distance (D_s) expressed in inches, and H_s is the standard or recommended character height at a viewing distance of 28 inches.

Example 10.1

A meter has to be read at a distance of 56 inches. The recommended numeral height at a viewing distance of 28 inches at low luminance is 0.31 inches. Calculate the numeral height for the viewing distance of 56 inches.

Substituting the specified data values into Equation 10.2 yields

$$\begin{aligned} H_C &= (0.31)(56) / 28 \\ &= 0.62 \text{ inches} \end{aligned}$$

Thus, the estimate for the numeral height for the specified viewing distance is 0.62 inches.

10.5.2.2 Formula 2

This formula was developed by Peters and Adams in 1959 to determine character height by taking into consideration factors such as illumination, importance of reading accuracy, viewing distance, and viewing conditions [16]. Thus, the character height is expressed by

$$CH = \theta VD + \alpha_i + \alpha_{VCi} \quad (10.3)$$

where CH is the character height in inches, VD is the viewing distance expressed in inches, α_i is the correction factor associated with importance. Its specified value for important items such as emergency labels is 0.075 and for other items is $\alpha_i = 0$. α_{VCi} is the correction factor for viewing conditions and illumination. Its recommended values for various corresponding viewing conditions and illuminations (in parentheses) are 0.06 (favorable reading conditions, above 1 foot-candle), 0.16 (unfavorable reading conditions, above 1 foot-candle), 0.16 (favorable reading conditions, below 1 foot-candle), and 0.26 (unfavorable reading conditions, below 1 foot-candle). θ is a constant whose specified value is 0.0022.

Example 10.2

Assume that the viewing distance of an instrument panel is estimated to be 42 inches. Calculate the height of the characters that should be used on the panel for $\alpha_i = 0.075$ and $\alpha_{VCi} = 0.06$.

Using the above specified values in Equation 10.3, we get

$$\begin{aligned} CH &= (0.0022)(42) + 0.075 + 0.06 \\ &= 0.2274 \end{aligned}$$

Thus, the height of the characters should be 0.2274 inches.

10.5.3 LIFTING LOAD ESTIMATION

This formula is concerned with estimating the maximum lifting load for a person. This information could be quite useful with respect to structuring various maintenance tasks. The maximum lifting load is expressed by [17]

$$MLL = k (IBMS) \quad (10.4)$$

where MLL is the maximum lifting load for a person, $IBMS$ is the isometric back muscle strength of the person, and k is a constant whose values are 1.1 and 0.95 for males and females, respectively.

10.5.4 GLARE CONSTANT ESTIMATION

For various maintainability-related tasks, glare can be a serious problem. The value of the glare constant can be calculated by using the following equation [18]:

$$\alpha_g = \frac{(L_s)^{1.6} (S_a)^{0.8}}{(AVG_d)^2 (L_{gb})} \quad (10.5)$$

where α_g is the glare constant value, L_s is the source luminance, S_a is the solid angle subtended at the eye by the source, AVG_d is the angle between the viewing direction and the glare source direction, and L_{gb} is the general background luminance.

10.6 PROBLEMS

1. Write an essay on human factors in maintainability.
2. List at least fifteen typical human behaviors.
3. What are the human sensory capabilities? Discuss at least three such capabilities in detail.
4. List at least five useful pointers for engineering designers concerning the application of body force and strength.
5. List factors to which attention should be given in maintainability design in regard to the use of auditory warning devices.
6. List important conditions for using auditory presentation.
7. List important conditions for using visual presentation.
8. Define decibel (dB).
9. The estimated viewing distance of an instrument panel is 50 inches. Calculate the height of the characters that should be used on the panel if the values of the importance correction factor and the illumination and viewing conditions correction factor are 0.075 and 0.16, respectively.
10. Write down the formula for estimating the maximum lifting load for a person.

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